

DEPARTMENT OF MECHANICAL ENGINEERING & MECHANICS
COLLEGE OF ENGINEERING & TECHNOLOGY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529

**NAVIER-STOKES CALCULATIONS OF
SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS**

By

Oktay Baysal, Principal Investigator

Final Report
For the period ended August 15, 1991

Prepared for
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Research Grant NAG-1-811
James L. Pittman, Technical Monitor
SMD-Aerothermal Loads Branch

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369



July 1991

(NASA-CR-185356) NAVIER-STOKES CALCULATIONS
OF SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS
Final Report, period ending 15 Aug. 1991
(Old Dominion Univ.) 32 p CSCL 200

N91-26488

Unclass
0025662

63/34

*Langley
GRANT
IN-34-CR
25662
p-32*

Final Report for the Grant NAG-1-811

NAVIER-STOKES CALCULATIONS OF SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS

**Oktay Baysal
Old Dominion University
Norfolk, Virginia**

Designing properly the nozzle and the lower aft end of a generic hypersonic vehicle powered by a scramjet engine is important in order to produce an effective propulsion. The interference of the exhaust on the control surfaces of the vehicle can have adverse effect on its stability. With this impetus and as a first step towards the design process, a comprehensive CFD effort has been conducted from 1987 to 1990 with the support of NASA Grant NAG-1-811.

The geometry of a wind tunnel model, which had been built for similar purposes, has been adopted in order to facilitate the necessary CFD code validation with the experimental results. Internal and external portions of the nozzle were included in the computational domain. All the calculations have assumed cold exhaust gases as have the wind tunnel tests. Also, the thermodynamic similitude has been maintained in one set of computations by using a cold gas mixture, which has a specific heat ratio (γ) equal to that of the hot exhaust gas.

Initially, two-dimensional Navier-Stokes computations have been performed, where the exhaust gas has been assumed to be air behaving as a perfect gas. Then, the exhaust gas was simulated by a mixture of Freon-12 and Argon, which required solving the Navier-Stokes

equations for four species (Nitrogen, Oxygen, Freon-12, Argon). This has allowed γ to be a field variable during the mixing of the multispecies gases, which have been assumed to be only thermally perfect with frozen chemistry. Two different mixing models have been used and comparisons between them as well as the perfect gas air calculations have been made to assess their relative merits. Finally, the three-dimensional Navier-Stokes computations were made for the full-span scramjet-nozzle-afterbody module. The computational results have been successfully compared with the wind tunnel data for the surface pressures (2-D air, 2-D multispecies, and 3-D air flows) and the pitot pressures of the off-surface flow (3-D airflow).

Details of the CFD methods and the results of the study have been presented in various national and international conferences as well as through the NASA briefings. The written versions of these presentations have been published in national journals, conference proceedings and pamphlets, and as a contractor report. Their list is given below. Two Navier-Stokes codes and a flow-adaptive grid generation code, which have been developed for this project, are available for interested users. Also, two master of science theses have been produced based on this study and the partial contents of a Ph.D. dissertation, which is in preparation, will include some of the results.

BIBLIOGRAPHY

Journal Papers:

Baysal, O., Hoffman, W. B., "Simulation of 3-D Shear Flow Around a Nozzle-Afterbody at High Speeds," ASME Journal of Fluids Engineering (log. no. RKA-3133), to appear in 1992.

Baysal, O., Eleshaky, M. E., Englund, W. C., "Computations of Multispecies Mixing Between Scramjet Nozzle Flow and Hypersonic Freestream," AIAA Journal of Propulsion and Power, (log. no. B1237) to appear in Vol. 7, No. 6, November/December 1991.

Conference Papers:

Baysal, O., Hoffman, W. B., "Simulation of 3-D Shear Flows Around a Nozzle-Afterbody at High Speeds," Advances in Numerical Simulation of Turbulent Flows (Ed.: I. Celik), ASME-FED, Vol. 117, Joint Meeting of ASME-JSME, Portland, OR, June 23-26, 1991, pp. 63-70.

Baysal, O. and Hoffman, W. B., "Computation of Hypersonic/Supersonic Flow Through a Single-Module Scramjet Nozzle," Proceedings of First International Conference on Computational Physics, IMACS, University of Colorado, Boulder, CO, June 11-16, 1990.

Baysal, O., Eleshaky, M. E., Engelund, W. C., "2-D and 3-D Mixing Flow Analyses of a Scramjet-Afterbody Configuration on Adaptive Grids," Proceedings of International Conference on Hypersonic Aerodynamics — The Royal Aeronautical Society, University of Manchester, U.K., September 4-6, 1989.

Baysal, O., Engelund, W. C., Eleshaky, M. E., "Adaptive Computations of Multispecies Mixing Between Scramjet Nozzle Flows and Hypersonic Freestream," AIAA Paper No. 89-0009, AIAA 27th Aerospace Sciences Meeting, Reno, NV, January 9-12, 1989.

Baysal, O., Engelund, W. C., Tatum, K. C., "Navier-Stokes Calculations of Scramjet-Afterbody Flowfields," Advances and Applications in CFD (Ed.: O. Baysal), ASME-FED, Vol. 66, Winter Annual Meeting, December 1988, pp. 49-60.

Pittman, J. L., Monta, W. J., Cubbage, J. M., Baysal, O., "An Experimental and Computational Simulation of a Scramjet Exhaust at Mach 6," Proceedings of the Fourth National Aero-space Plane Technology Symposium, Monterey, CA, February 17-19, 1988.

Reports:

Baysal, O., Engelund, W. C., "Viscous Computations of Cold Air/Air Flow Around Scramjet-Nozzle Afterbody," Prospective NASA-CR, NASA LaRC, Hampton, VA, February 1991.

Baysal, O., Miller, D. S., "Analysis of Scramjet Nozzle-Afterbody Flowfield," Research and Technology, NASA-TM-4243, Langley Research Center, 1990, pp. 109-110.

Baysal, O., Engelund, W. C., Tatum, K. E., "Navier-Stokes Calculations of Scramjet-Afterbody Flowfields," NASP Report CR-1034, NASA LaRC, Hampton, VA, November 1988.

SIMULATION OF 3-D SHEAR FLOW AROUND A NOZZLE-AFTERBODY AT HIGH SPEEDS

**Oktay Baysal and Wendy B. Hoffman
Old Dominion University, Norfolk, VA 23529**

SYMPOSIUM ON ADVANCES IN NUMERICAL SIMULATION OF TURBULENT FLOWS

**Joint Meeting of the American Society of Mechanical Engineers (ASME)
and Japanese Society of Mechanical Engineers (JSME)**

**Portland, Oregon
June 23-26, 1991**

**COMPUTATIONS OF MULTISPECIES MIXING BETWEEN
SCRAMJET NOZZLE FLOW AND HYPERSONIC FREESTREAM**

Oktay Baysal

Mohamed E. Elshaky

Walter C. Englund

Old Dominion University

Mechanical Engineering and Mechanics Department

Norfolk, Virginia 23529-0247

Tel. (804) 683-3720

This paper is the revised version of the paper submitted on October 27, 1989, to J. Propulsion and Power. The reference number for AIAA Journal of Propulsion and Power is B1237.

March 1991

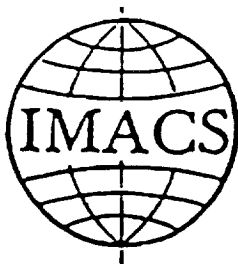
IMACS 1ST INTERNATIONAL CONFERENCE ON COMPUTATIONAL PHYSICS

Sponsored by

**IMACS
(Association Internationale
Pour Les Mathematiques
et Calculateurs en Simulation)**

and the

**University of Colorado at Boulder
Mathematical Physics Ph.D. Program**



Conference Program

**University of Colorado at Boulder
Boulder, Colorado**

June 11-15, 1990

COMPUTATION OF SUPERSONIC-HYPERSONIC FLOW THROUGH A SINGLE-MODULE SCRAMJET NOZZLE

Oktaý Baysal and Wendy B. Hoffman

Department of Mechanical Engineering and Mechanics
Old Dominion University, Norfolk, VA 23529

ABSTRACT

A computational investigation is conducted to study the expansion of a supersonic air flow through an internal-external nozzle and its mixing with a hypersonic air flow. The impetus is to help the design of the nozzle-afterbody section of a hypersonic transport vehicle which is powered by a scramjet engine. Three-dimensional compressible Navier-Stokes equations are solved by the finite-volume and alternating-direction-implicit method. The convective and the pressure terms are differenced by an upwind-biased algorithm which uses the flux-difference splitting and various flux limiters. The Reynolds stresses are modeled algebraically. The simulated flowfield also allows detailed analyses of a supersonic duct flow, a supersonic flow through an asymmetric internal nozzle, a hypersonic flow over a double-corner, and three-dimensional shear layers. The computed pressure distributions compare favorably with the experimentally obtained surface and off-surface flow surveys.

INTRODUCTION

Propulsion-airframe integration for hypersonic airbreathing vehicles is an important feature for the design of a national aero-space plane configuration. The lower afterbody expands the supersonic exhaust gases from the scramjet engine, therefore it becomes a part of the nozzle. This strong coupling between the engine and the airframe necessitates a combined analysis of internal and external flows. The hypersonic freestream and the supersonic exhaust flow mix through a shear layer, where mass, momentum, and energy transfers occur. The interference of the exhaust on the control surfaces of the aircraft can have adverse effects on the stability of the aircraft. Therefore, some method of simulating this type of flow is required to properly design the nozzle and the afterbody region.

A simplified configuration is assumed to model the single-module scramjet nozzle and afterbody. A rectangular duct precedes the internal nozzle, which has a 12° upper surface and a 20° lower surface. The external part of the nozzle is bounded by a 20° ramp and a vertical reflection plate. The external hypersonic flow is initially over a double-corner formed by the reflection plate, the top surface of the nozzle, the exterior of the nozzle sidewall, and a side flat plate. The viscous effects become dominant in all the corner regions. Then both of the flows expand over the 20° ramp. The supersonic jet expands in the axial, the normal, and the spanwise directions as it clears the exit plane. A three dimensional shear layer structure is formed between these coflowing streams which are at different speeds.

NASA CONTRACTOR REPORT

VISCOUS COMPUTATIONS OF COLD AIR/AIR
FLOW AROUND SCRAMJET NOZZLE-AFTERBODY

Oktay Baysal, Principal Investigator

Walter C. Engelund

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369

GRANT NAG-1-811
MARCH 1990



INTERNATIONAL CONFERENCE ON HYPERSONIC AERODYNAMICS



THREE DAY CONFERENCE

MONDAY 4 – WEDNESDAY 6 SEPTEMBER 1989

AT THE

UNIVERSITY OF MANCHESTER

THE ROYAL AERONAUTICAL SOCIETY

2-D AND 3-D MIXING FLOW ANALYSES
OF A SCRAMJET-AFTERBODY CONFIGURATION

Oktay Baysal
Mohamed E. Eleshaky
Walter C. Englund

Old Dominion University
Mechanical Engineering and Mechanics Department
Norfolk, Virginia 23529-0247 USA

Paper No. 14

International Conference on Hypersonic Aerodynamics
University of Manchester
Manchester, U.K.

September 4-6, 1989

Organized by
THE ROYAL AERONAUTICAL SOCIETY

AIAA '89

AIAA-89-0009

Adaptive Computations of Multispecies Mixing Between Scramjet Nozzle Flows and Hypersonic Freestream

Oktay Baysal

Walter C. Engelund

Mohamed E. Eleshaky

Old Dominion University, Norfolk, Virginia

James L. Pittman

NASA Langley Research Center,
Hampton, Virginia

27th Aerospace Sciences Meeting

January 9-12, 1989/Reno, Nevada

UNCLASSIFIED

NASP Contractor Report 1034

2-D Navier-Stokes Calculations of Scramjet- Afterbody Flowfields

Oktay Baysal,
Walter C. Engelund,
and Kenneth E. Tatum

Grant NAG1-811

December 1988

Notice

This document is for quick release to organizations participating in the National Aero-Space Plane Program (NASP). Customary editing and review have been waived in order to provide rapid dissemination of data and preliminary results. Distribution is by authority of the NASP Joint Program Office, Wright-Patterson AFB, OH.



OLD DOMINION UNIVERSITY

Norfolk, Virginia 23529

UNCLASSIFIED

ORIGINAL PAGE IS
OF POOR QUALITY

ADVANCES AND APPLICATIONS IN COMPUTATIONAL FLUID DYNAMICS

presented at

THE WINTER ANNUAL MEETING OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
CHICAGO, ILLINOIS
NOVEMBER 27-DECEMBER 2, 1988

sponsored by

THE FLUIDS ENGINEERING DIVISION, ASME

edited by

O. BAYSAL
OLD DOMINION UNIVERSITY

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center 345 East 47th Street New York, N.Y. 10017

Navier-Stokes Calculations of Scramjet-Afterbody Flowfields

by

O. Baysal¹
W. C. Engelund²

Department of Mechanical Engineering and Mechanics
Old Dominion University
Norfolk, Virginia 23529

K. E. Tatum³

NASA Langley Research Center,
Hampton, Virginia 23665.

Symposium on Advances and Applications
in Computational Fluid Dynamics

1988 Winter Annual Meeting of ASME
November 27-December 2, Chicago, Illinois
(ASME Special Publications, FED-Volume)

66

¹Associate Professor, Mech. Eng. & Mech. Dept.

²Graduate Research Assistant, Mech. Eng. & Mech. Dept.

³Research Engineer, PRC Kentron, SHAB/HSAD

UNCLASSIFIED

AN EXPERIMENTAL COLD GAS SIMULATION OF A SCRAMJET EXHAUST AT MACH 6 (U)

James L. Pittman,
William J. Monta
NASA Langley Research Center
Hampton, Virginia

James M. Cubbage
Vigyan Research Associates, Inc.
Hampton, Virginia

Oktay Baysal
Old Dominion University
Norfolk, Virginia

Fourth National Aero-Space Plane Technology Symposium
Monterey, California
February 17-19, 1988

UNCLASSIFIED

DEPARTMENT OF MECHANICAL ENGINEERING & MECHANICS
COLLEGE OF ENGINEERING & TECHNOLOGY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529

**NAVIER-STOKES CALCULATIONS OF
SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS**

By

Oktay Baysal, Principal Investigator

Final Report
For the period ended August 15, 1991

Prepared for
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Research Grant NAG-1-811
James L. Pittman, Technical Monitor
SMD-Aerothermal Loads Branch

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369



July 1991

Final Report for the Grant NAG-1-811

NAVIER-STOKES CALCULATIONS OF SCRAMJET-NOZZLE-AFTERBODY FLOWFIELDS

**Oktay Baysal
Old Dominion University
Norfolk, Virginia**

Designing properly the nozzle and the lower aft end of a generic hypersonic vehicle powered by a scramjet engine is important in order to produce an effective propulsion. The interference of the exhaust on the control surfaces of the vehicle can have adverse effect on its stability. With this impetus and as a first step towards the design process, a comprehensive CFD effort has been conducted from 1987 to 1990 with the support of NASA Grant NAG-1-811.

The geometry of a wind tunnel model, which had been built for similar purposes, has been adopted in order to facilitate the necessary CFD code validation with the experimental results. Internal and external portions of the nozzle were included in the computational domain. All the calculations have assumed cold exhaust gases as have the wind tunnel tests. Also, the thermodynamic similitude has been maintained in one set of computations by using a cold gas mixture, which has a specific heat ratio (γ) equal to that of the hot exhaust gas.

Initially, two-dimensional Navier-Stokes computations have been performed, where the exhaust gas has been assumed to be air behaving as a perfect gas. Then, the exhaust gas was simulated by a mixture of Freon-12 and Argon, which required solving the Navier-Stokes

equations for four species (Nitrogen, Oxygen, Freon-12, Argon). This has allowed γ to be a field variable during the mixing of the multispecies gases, which have been assumed to be only thermally perfect with frozen chemistry. Two different mixing models have been used and comparisons between them as well as the perfect gas air calculations have been made to assess their relative merits. Finally, the three-dimensional Navier-Stokes computations were made for the full-span scramjet-nozzle-afterbody module. The computational results have been successfully compared with the wind tunnel data for the surface pressures (2-D air, 2-D multispecies, and 3-D air flows) and the pitot pressures of the off-surface flow (3-D airflow).

Details of the CFD methods and the results of the study have been presented in various national and international conferences as well as through the NASA briefings. The written versions of these presentations have been published in national journals, conference proceedings and pamphlets, and as a contractor report. Their list is given below. Two Navier-Stokes codes and a flow-adaptive grid generation code, which have been developed for this project, are available for interested users. Also, two master of science theses have been produced based on this study and the partial contents of a Ph.D. dissertation, which is in preparation, will include some of the results.

BIBLIOGRAPHY

Journal Papers:

Baysal, O., Hoffman, W. B., "Simulation of 3-D Shear Flow Around a Nozzle-Afterbody at High Speeds," ASME Journal of Fluids Engineering (log. no. RKA-3133), to appear in 1992.

Baysal, O., Eleshaky, M. E., Englund, W. C., "Computations of Multispecies Mixing Between Scramjet Nozzle Flow and Hypersonic Freestream," AIAA Journal of Propulsion and Power, (log. no. B1237) to appear in Vol. 7, No. 6, November/December 1991.

Conference Papers:

Baysal, O., Hoffman, W. B., "Simulation of 3-D Shear Flows Around a Nozzle-Afterbody at High Speeds," Advances in Numerical Simulation of Turbulent Flows (Ed.: I. Celik), ASME-FED, Vol. 117, Joint Meeting of ASME-JSME, Portland, OR, June 23-26, 1991, pp. 63-70.

Baysal, O. and Hoffman, W. B., "Computation of Hypersonic/Supersonic Flow Through a Single-Module Scramjet Nozzle," Proceedings of First International Conference on Computational Physics, IMACS, University of Colorado, Boulder, CO, June 11-16, 1990.

Baysal, O., Eleshaky, M. E., Engelund, W. C., "2-D and 3-D Mixing Flow Analyses of a Scramjet-Afterbody Configuration on Adaptive Grids," Proceedings of International Conference on Hypersonic Aerodynamics — The Royal Aeronautical Society, University of Manchester, U.K., September 4-6, 1989.

Baysal, O., Engelund, W. C., Eleshaky, M. E., "Adaptive Computations of Multispecies Mixing Between Scramjet Nozzle Flows and Hypersonic Freestream," AIAA Paper No. 89-0009, AIAA 27th Aerospace Sciences Meeting, Reno, NV, January 9-12, 1989.

Baysal, O., Engelund, W. C., Tatum, K. C., "Navier-Stokes Calculations of Scramjet-Afterbody Flowfields," Advances and Applications in CFD (Ed.: O. Baysal), ASME-FED, Vol. 66, Winter Annual Meeting, December 1988, pp. 49-60.

Pittman, J. L., Monta, W. J., Cubbage, J. M., Baysal, O., "An Experimental and Computational Simulation of a Scramjet Exhaust at Mach 6," Proceedings of the Fourth National Aero-space Plane Technology Symposium, Monterey, CA, February 17-19, 1988.

Reports:

Baysal, O., Engelund, W. C., "Viscous Computations of Cold Air/Air Flow Around Scramjet-Nozzle Afterbody," Prospective NASA-CR, NASA LaRC, Hampton, VA, February 1991.

Baysal, O., Miller, D. S., "Analysis of Scramjet Nozzle-Afterbody Flowfield," Research and Technology, NASA-TM-4243, Langley Research Center, 1990, pp. 109-110.

Baysal, O., Engelund, W. C., Tatum, K. E., "Navier-Stokes Calculations of Scramjet-Afterbody Flowfields," NASP Report CR-1034, NASA LaRC, Hampton, VA, November 1988.

SIMULATION OF 3-D SHEAR FLOW AROUND A NOZZLE-AFTERBODY AT HIGH SPEEDS

**Oktay Baysal and Wendy B. Hoffman
Old Dominion University, Norfolk, VA 23529**

SYMPOSIUM ON ADVANCES IN NUMERICAL SIMULATION OF TURBULENT FLOWS

**Joint Meeting of the American Society of Mechanical Engineers (ASME)
and Japanese Society of Mechanical Engineers (JSME)**

**Portland, Oregon
June 23-26, 1991**

**COMPUTATIONS OF MULTISPECIES MIXING BETWEEN
SCRAMJET NOZZLE FLOW AND HYPERSONIC FREESTREAM**

Oktay Baysal

Mohamed E. Elshaky

Walter C. Englund

Old Dominion University

Mechanical Engineering and Mechanics Department

Norfolk, Virginia 23529-0247

Tel. (804) 683-3720

This paper is the revised version of the paper submitted on October 27, 1989, to J. Propulsion and Power. The reference number for AIAA Journal of Propulsion and Power is B1237.

March 1991

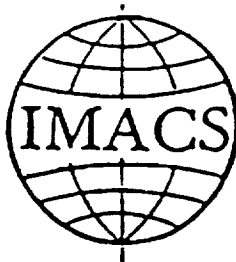
IMACS 1ST INTERNATIONAL CONFERENCE ON COMPUTATIONAL PHYSICS

Sponsored by

**IMACS
(Association Internationale
Pour Les Mathematiques
et Calculateurs en Simulation)**

and the

**University of Colorado at Boulder
Mathematical Physics Ph.D. Program**



Conference Program

**University of Colorado at Boulder
Boulder, Colorado**

June 11-15, 1990

COMPUTATION OF SUPERSONIC-HYPERSONIC FLOW THROUGH A SINGLE-MODULE SCRAMJET NOZZLE

Oktay Baysal and Wendy B. Hoffman
Department of Mechanical Engineering and Mechanics
Old Dominion University, Norfolk, VA 23529

ABSTRACT

A computational investigation is conducted to study the expansion of a supersonic air flow through an internal-external nozzle and its mixing with a hypersonic air flow. The impetus is to help the design of the nozzle-afterbody section of a hypersonic transport vehicle which is powered by a scramjet engine. Three-dimensional compressible Navier-Stokes equations are solved by the finite-volume and alternating-direction-implicit method. The convective and the pressure terms are differenced by an upwind-biased algorithm which uses the flux-difference splitting and various flux limiters. The Reynolds stresses are modeled algebraically. The simulated flowfield also allows detailed analyses of a supersonic duct flow, a supersonic flow through an asymmetric internal nozzle, a hypersonic flow over a double-corner, and three-dimensional shear layers. The computed pressure distributions compare favorably with the experimentally obtained surface and off-surface flow surveys.

INTRODUCTION

Propulsion-airframe integration for hypersonic airbreathing vehicles is an important feature for the design of a national aero-space plane configuration. The lower afterbody expands the supersonic exhaust gases from the scramjet engine, therefore it becomes a part of the nozzle. This strong coupling between the engine and the airframe necessitates a combined analysis of internal and external flows. The hypersonic freestream and the supersonic exhaust flow mix through a shear layer, where mass, momentum, and energy transfers occur. The interference of the exhaust on the control surfaces of the aircraft can have adverse effects on the stability of the aircraft. Therefore, some method of simulating this type of flow is required to properly design the nozzle and the afterbody region.

A simplified configuration is assumed to model the single-module scramjet nozzle and afterbody. A rectangular duct precedes the internal nozzle, which has a 12° upper surface and a 20° lower surface. The external part of the nozzle is bounded by a 20° ramp and a vertical reflection plate. The external hypersonic flow is initially over a double-corner formed by the reflection plate, the top surface of the nozzle, the exterior of the nozzle sidewall, and a side flat plate. The viscous effects become dominant in all the corner regions. Then both of the flows expand over the 20° ramp. The supersonic jet expands in the axial, the normal, and the spanwise directions as it clears the exit plane. A three dimensional shear layer structure is formed between these coflowing streams which are at different speeds.

NASA CONTRACTOR REPORT

**VISCOUS COMPUTATIONS OF COLD AIR/AIR
FLOW AROUND SCRAMJET NOZZLE-AFTERBODY**

Oktaý Baysal, Principal Investigator

Walter C. Englund

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508-0369

**GRANT NAG-1-811
MARCH 1990**



National Aeronautics and
Space Administration

INTERNATIONAL CONFERENCE ON HYPERSONIC AERODYNAMICS



THREE DAY CONFERENCE

MONDAY 4 – WEDNESDAY 6 SEPTEMBER 1989

AT THE

UNIVERSITY OF MANCHESTER

THE ROYAL AERONAUTICAL SOCIETY

2-D AND 3-D MIXING FLOW ANALYSES
OF A SCRAMJET-AFTERBODY CONFIGURATION

Oktay Baysal
Mohamed E. Elshaky
Walter C. Engelund

Old Dominion University
Mechanical Engineering and Mechanics Department
Norfolk, Virginia 23529-0247 USA

Paper No. 14

International Conference on Hypersonic Aerodynamics
University of Manchester
Manchester, U.K.

September 4-6, 1989

Organized by
THE ROYAL AERONAUTICAL SOCIETY

AIAA '89

AIAA-89-0009

Adaptive Computations of Multispecies Mixing Between Scramjet Nozzle Flows and Hypersonic Freestream

Oktay Baysal

Walter C. Engelund

Mohamed E. Eleshaky

Old Dominion University, Norfolk, Virginia

James L. Pittman

NASA Langley Research Center,
Hampton, Virginia

27th Aerospace Sciences Meeting

January 9-12, 1989/Reno, Nevada

ORIGINAL PAGE IS
OF POOR QUALITY

UNCLASSIFIED

NASP Contractor Report 1034

2-D Navier-Stokes Calculations of Scramjet- Afterbody Flowfields

Oktay Baysal,
Walter C. Engelund,
and Kenneth E. Tatum

Grant NAG1-811

December 1988

Notice

This document is for quick release to organizations participating in the National Aero-Space Plane Program (NASP). Customary editing and review have been waived in order to provide rapid dissemination of data and preliminary results. Distribution is by authority of the NASP Joint Program Office, Wright-Patterson AFB, OH.



OLD DOMINION UNIVERSITY

Norfolk, Virginia 23529

ORIGINAL PAGE IS
OF POOR QUALITY

UNCLASSIFIED

ADVANCES AND APPLICATIONS IN COMPUTATIONAL FLUID DYNAMICS

presented at

THE WINTER ANNUAL MEETING OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
CHICAGO, ILLINOIS
NOVEMBER 27-DECEMBER 2, 1988

sponsored by

THE FLUIDS ENGINEERING DIVISION, ASME

edited by

O. BAYSAL
OLD DOMINION UNIVERSITY

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center 345 East 47th Street New York, N.Y. 10017

Navier-Stokes Calculations of Scramjet-Afterbody Flowfields

by

O. Baysal¹
W. C. Engelund²

Department of Mechanical Engineering and Mechanics
Old Dominion University
Norfolk, Virginia 23529

K. E. Tatum³

NASA Langley Research Center,
Hampton, Virginia 23665.

Symposium on Advances and Applications
in Computational Fluid Dynamics

1988 Winter Annual Meeting of ASME
November 27-December 2, Chicago, Illinois
(ASME Special Publications, FED-Volume)

66

¹Associate Professor, Mech. Eng. & Mech. Dept.

²Graduate Research Assistant, Mech. Eng. & Mech. Dept.

³Research Engineer, PRC Kentron, SHAB/HSAD

UNCLASSIFIED

AN EXPERIMENTAL COLD GAS SIMULATION OF A SCRAMJET EXHAUST AT MACH 6 (U)

James L. Pittman,
William J. Monta
NASA Langley Research Center
Hampton, Virginia

James M. Cubbage
Vigyan Research Associates, Inc.
Hampton, Virginia

Oktay Baysal
Old Dominion University
Norfolk, Virginia

Fourth National Aero-Space Plane Technology Symposium
Monterey, California
February 17-19, 1988

UNCLASSIFIED